American Fisheries Society Symposium 41:000–000, 2005

Place Matters: Spatial Tools for Assessing the Socioeconomic Implications of Marine Resource Management Measures on the Pacific Coast of the United States

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Abstract. Fishery management measures, such as the reduction of excess fishing capacity, and conservation measures, such as networks of marine protected areas, have considerable socioeconomic impacts. Users of marine resources—commercial and recreational fishermen, boaters, divers, and others—experience direct and indirect costs and benefits from such measures, notably foregone earnings and changing economic opportunities. In this paper, we present results and tools from a 2-year project to build an integrated, spatially explicit analytical framework for assessing management options such as fleet reductions and area closures on the West Coast of the United States, using the groundfish fleet as an example. After developing an extensive relational database comprising fishery-dependent, ecological, and socioeconomic data, we built a regional geographic information system (GIS) and assessed the relative impacts of five management scenarios. The results are spatially explicit and specific to particular communities, gear groups, fishing fleets, and ecological habitats, thus allowing decision makers to consider a range of issues that present themselves in management situations. The GIS makes for an intuitive interface that allows for participatory and consensus-oriented approaches to fishery management.

Introduction

The challenges facing West Coast fisheries are emblematic of the difficulties associated with shifting marine resource management to an ecosystem perspective (i.e., the explicit consideration of habitat and bathymetric associations of the fish species in question, as well as their assemblages). Legacies of past decisions create considerable structural challenges, notably in the form of overcapacity, while relatively new fishery management and conservation tools, such as area closures, require a reinterpretation of existing data sets, if not the collection of new data altogether. These challenges are compounded by the "catching up" required of socioeconomic considerations in fishery management, which historically has been dominated by stock assessments and biological models. Yet the larger the challenges facing fishery managers, the more socioeconomic concerns become important. A recent National Academy of Sciences study on marine protected areas went so far as to say that successful implementation of ecosystem-based management measures is impeded by the lack of attention to, and careful consideration of, the socioeconomic implications of proposed mea-

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sures (NRC 2001). In this paper, we introduce an approach for assessing socioeconomic impacts of both structural changes and routine management measures on the West Coast, using the example of the groundfish fishery.

Commercial fisheries off the coasts of Washington, Oregon, and California are undergoing dramatic changes. Whether pelagic species, groundfish, or salmon *Oncorhynchus* spp., landings and revenues have been declining for most fisheries over the last 10 years. In this paper, we focus on the groundfish fishery, which comprises more than 80 species of soles (e.g., Dover sole *Microstomus pacificus* and petrale sole *Eopsetta jordani*), flounders (e.g., arrowtooth flounder *Atheresthes stomias*), rockfish *Sebastes* spp., sablefish *Anoplopoma fimbria*, and Pacific hake *Merluccius productus* (also known as Pacific whiting) managed by the Pacific Fishery Management Council (PFMC). Commercial fisheries for groundfish date back to the 19th century and have been prosecuted with gear types including hook and line, pots, traps, and trawl nets. These gear types have evolved considerably over time and are characterized by one main distinction between mobile and fixed gear types: typically, trawl gear is used with relatively high volume, low value target species such as Pacific hake, while hook-and-line caught rockfish command some of the highest market values. After a period of expansion following the passage of the Magnuson-Stevens Fisheries Conservation and Management Act of 1976 and the subsequent "Americanization" of the fishery, landings of groundfish have declined over the past 20 years. Some species have declined to levels that trigger stringent rebuilding plans and bycatch avoidance measures, affecting the rest of the groundfish management complex. These measures, in turn, threaten the economic viability of the fishery, which was declared a federal disaster in 2000.

In response to the worsening crisis, the PFMC adopted a strategic plan, "Transition to Sustainability," that lays out a set of management priorities to safeguard the future of the fishery (PFMC 2000a). The top priorities set forth in the plan are the reduction of the groundfish fleet by at least 50% in each fishery sector and the viable balancing of ecological and economic considerations for the fishery. Implicit in this plan is a consensus among fishermen, scientists, and managers that the expansion of the fleet in the 1970s has resulted in a fleet that is too large to profitably harvest the allocations deemed biologically sustainable. In the 3 years since the adoption of the strategic plan, however, the council agenda has been dominated by the increasingly more urgent day-to-day business of responding to stock assessments and the harvest restrictions they necessitate.

This mismatch between short-term management needs and strategic considerations for restructuring the fishery was further exacerbated by the area closures first implemented with the 2002 in-season closures of large sections of the continental shelf. Essentially, this is an acknowledgment that traditional trip limit management is not effective at reducing bycatch of some of the most threatened species of rockfish such as canary rockfish *Sebastes pinniger* and darkblotched rockfish *Sebastes crameri*. Instead, the fishery is increasingly managed on the basis of time and area closures designed to minimize the chance of encountering populations of threatened species. In a considerable departure from single-species-driven management, these measures may well be the first wave of ecosystem-based management principles and may constitute early steps towards ecosystem-based fishery management plans (Field et al. 2001).

While spatiotemporal management measures, such as shelf closures, appear better aligned with ecosystem mandates for marine resource management (Ecosystems Principles Advisory Panel 1999; NRC 2001), they pose considerable challenges to the management process. Rather than having the leisure to design ecosystem management principles for fisheries from first principles, federal and state agencies have to act now, within the current paradigm of fishery management. This is further complicated by the absence of technical and technological capacity in many management regions to address spatial and temporal aspects of fishery management. In particular, fishery-dependent and independent data that have been collected on the West Coast for over 20 years are not typically mined or interpreted in spatially explicit ways. This is part of a larger issue identified, for example, in a recent National Research Council study. In reference to legally mandated essential fish habitat assessments and novel management tools such as marine protected areas, the study notes that "NMFS [National Marine Fisheries Service; now National Oceanic and Atmospheric Administration Fisheries] and its partner agencies should integrate existing data [. . .] to provide geographic databases for major fishing grounds" (NRC 2002:3).

In addition to the lack of spatial integration of existing data, there is the added problem of lacking or insufficient economic and other "soft" data about coastal communities and the effects of fishery management measures on them. With the groundfish crisis unfolding, the socioeconomic data deficits are well known and documented (PFMC 2000b) but have hardly been addressed in the interim. The problem at hand, therefore, is fourfold: declining stocks, excess capacity, lack of integrated databases for assessing spatiotemporal management measures, and lack of socioeconomic data for assessing effects on coastal communities. In this paper, we report on a model we developed to address this nexus of issues, with the aim of providing decision-support tools for managers and communities on the West Coast.

In the following section, we outline a spatial framework for linking ecological, fisheries, and socioeconomic information that utilizes existing, readily available data. We then discuss the application of this approach to the overcapacity issue in the West Coast groundfish fishery and present results from a static comparison of different management scenarios.

The OCEAN Framework

In order to meet the fourfold challenge facing ecosystem-based fisheries management—managing declining stocks in the presence of overcapitalized fleet with data that are not sufficiently spatially explicit for ecosystem-based management or do not exist at all—we designed a framework for jointly addressing these issues. The OCEAN (Ocean Communities Economic/Ecological/Equity ANalysis) framework comprises a set of linked, spatially explicit models. The three Es—economics, ecology, and equity—represent Ecotrust's mission to promote economic development that is both ecologically sustainable and equitable (Scholz 2003). It is rooted in the growing literature of marine geographic information system (GIS) models that are being developed to address a host of oceanographic, coastal, and fisheries issues and problems (Kruse et al. 2001; Breman 2002; Valavanis 2002; Green and King 2003). The OCEAN framework is essentially a meta-analytical tool for combining a range of data, using a relational database architecture and GIS as the "common currency."

The centerpiece of our analysis is the modeling of data that are already available in spatially explicit formats, as well as the spatial interpretation of other, not yet spatially explicit, information. The challenge is to organize data from diverse sources, in diverse formats, and of varying quality and to integrate them into a single framework. We began work on OCEAN by reviewing existing sources of data and compiling them into one relational database. Where necessary, we built new geographic models to spatially interpret data, especially those pertaining to the distribution of fishing effort. Combining bathymetry and habitat information with fishing effort and species distributions then formed the basis for analyzing which vessels fish where, with what gear, and targeting what species. To this, in turn, we added an economic model for assessing the relative socioeconomic impacts of different management scenarios. We present here the first, static, "version 1.0" of OCEAN.

Data Sources

Fishery-dependent data on landings, revenues, and vessels are collected by the three states in our study area (Washington, Oregon, and California) and stored in the Pacific Fisheries Information Network (PacFIN) of the Pacific States Marine Fisheries Commission (Sampson and Crone 1997). For the project on groundfish fleet restructuring presented here, we obtained 14 years of data summarized to individual vessels by port, gear, species, and year for all vessels fishing for groundfish. The availability and quality of data for different fishing sectors varied considerably. The trawl fishery is best documented, with at-sea logbooks augmenting the information on catch and landings that is reported port side in the landing tickets. Trawl logbooks are spatially explicit, with trawl set points recorded for individual trawls (typically referenced by 10-min blocks). Trawl duration is also recorded, thus providing a measure of effort. The trawl logbook data, however, have two major limitations. First, although skippers record trawl endpoints, these are not transcribed into the PacFIN database. Since there is as yet no comprehensive vessel monitoring system in place on the West Coast, estimating the precise extent of trawl activity remains rather difficult. We tried to ameliorate this with a model based on the trawl set points and trawl duration. Essentially, we constrain vectors of possible trawl directions by using habitat and bathymetric considerations for each recorded tow. The result is a density map of probable tow tracks. This model is not discussed further here, but forms—together with a more detailed discussion of the effort model built on the landing receipts—the basis for a forthcoming paper. Secondly, although the same vessel identifiers are used in both data collection efforts, there remain considerable gaps between the logbook and landing receipts record sets (Fox and Starr 1996; Sampson and Crone 1997). For our analysis, we used a record set provided by PacFIN in which the records were already matched up, thus subsuming any associated uncertainty.

No such logbooks exist for the fixed gear sectors of the fishery, making landing receipts the only source of information. These are less spatially explicit and typically contain no measure of fishing intensity or effort. With the exception of California, where all landings are recorded in 10-min blocks, the spatial unit of PacFIN landing receipts are statistical areas defined by the now defunct International North Pacific Fisheries Commission (INPFC). There are only 12 INPFC areas for the entire West Coast from Cape Flattery in Washington to the Mexico border, each covering thousands of square miles. We developed an iterative algorithm (described below), drawing on all the data assembled in OCEAN to make the landing receipts more spatially explicit. This, in turn, is a prerequisite for considering the socioeconomic implications of management measures, such as the in-season shelf closure, which affect vessels that used to fish in the now closed areas.

Bathymetry and other data on oceanographic characteristics were obtained from the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), and state agencies such as the California Department of Fish and Game. One key component for ecosystem management is habitat and the consideration of the impact of fishing activities on different parts of the seafloor. The continental shelf in our study area has been the subject of considerable habitat mapping efforts, such as the USGS habitat GIS for the Monterey Bay National Marine Sanctuary (Wong and Eittreim 2001) and the ongoing effort in support of NOAA Fisheries' Essential Fish Habitat Environmental Impact Statement (*www.nwr.noaa.gov/1sustfsh/groundfish/eis_efh/efh/*). Using known habitat associations for various fish species, as well as the depth constraints on particular types of fishing gear, habitat data can be used to relate fishing effort to particular areas.

The scientific surveys conducted by NOAA Fisheries over the past 25 years are a major source of fishery-independent data. We obtained all available years of shelf and slope surveys from the NOAA Alaska Fisheries Science Center. The NOAA research vessels using trawl gear record the total number, size and age distribution, and weight of fish sampled along fixed transects (Lauth 2000; Weinberg et al. 2002). Because of the consistency of the sampling protocol the trawl surveys generate a comprehensive picture of species abundance, at least along the trawl transects. One obvious limitation of the NOAA surveys is that they are conducted in summer months, using trawl gear. There are few remedies for this situation. In other areas, notably waters of Alaska, it would be possible to use data from surveys conducted by the International Pacific Halibut Commission using fixed gear. This would generate more representative species distribution maps. In the surveys, species and abundance (number of fish per species) are recorded for each trawl start point. We extracted individual records of species targeted in the commercial fishery, normalized these by total effort, and generated species-specific density maps. Following an approach developed by NOAA's Biogeography Group (NOAA's National Centers for Coastal Ocean Science and National Marine Sanctuaries Program 2002), we summarized these to 9-km × 9-km analysis units and derived single, cumulative species distribution maps for each target species.

The final component of OCEAN concerns the linkage between fishing activity and coastal communities. The obvious points of contact are the landing ports, where vessels sell their catch to fish buyers and processors. Together with other marine services and businesses, processing is a major contributor to income generated in coastal communities. This aspect of socioeconomic impacts is already captured in a regional input–output model used by the PFMC to assess the economic impacts of fishery policy (Jensen 1996, 1998). The Fisheries Economic Assessment model (FEAM) belongs to a class of regional input–output models that treat the economic activity in a region as a set of interconnected sectors. This is a form of input–output modeling pioneered by Wassily Leontief to describe the U.S. economy (see Hewings 1985 for an overview). Each dollar generated in one sector has a "multiplier effect" because it generates economic activity in other sectors. For example, fish are landed, and the vessel is paid a price per pound for its catch. Out of this exvessel revenue, crew shares, maintenance, and moorage costs and other expenses are paid, which in turn generate personal income and revenues for the port district and other marine-related businesses. The FEAM estimates these effects for the two primary sectors affected by fishing activity (i.e., harvesters [fishermen and their families] and processors). We summarized these model outputs in a set of spreadsheets which we integrated into OCEAN. This allowed us to consider the income impacts of changes in landings in a port resulting from particular management scenarios.

A key limitation of the FEAM analysis is that it is static in nature and only provides an incomplete snapshot in time. It is premised on the landings and revenues generated by the fishing fleet but is silent on alternative sources of revenues in coastal communities, such as tourism. Unlike other regional input–output models, FEAM is not designed to assess employment effects. Furthermore, there are a host of considerations over and beyond economic impacts that are of importance to coastal communities and managers but are not yet routinely assessed. For example, the lifestyle aspects of fishing communities are important (Hanna et al. 2000), as are concerns about the social and cultural resilience of ports and towns in response to the structural changes in the fishery (Langdon-Pollock 2002). By way of addressing these concerns, and to lay the groundwork for more in-depth analysis of coastal communities in future applications of OCEAN, we incorporated census statistics as well as qualitative information (Scholz 2003).

Methods

Our analytical approach centers on the spatial association of data. This kind of analysis has been used in other marine applications of GIS, for example, to assess the location of fishing effort close to shore (Caddy and Carocci 1999) or to detect trends in global fishery statistics (Watson and Pauly 2001). The OCEAN approach operates at an intermediate, regional scale, with explicit consideration of the socioeconomic impacts in coastal communities. Conceptually, OCEAN is a multilayered information system comprising geographic and other data in a "smart map" environment. The system can be queried from within any one data layer (e.g., to find particular vessels or gear groups fishing in a habitat of interest or to generate the exvessel revenues associated with a particular species). Information can be manipulated on map-based user interfaces, and results are summarized in map formats.

The bulk of our analytical work consists of assembling information for the groundfish fishery and developing models for integrating and interpreting data that, more often than not, were recorded at widely disparate spatial scales, if at all. A central part of OCEAN is a fishing effort sub-model that we describe in some detail here. In the next section, we present results from an analysis of coast-wide impacts of various capacity reduction scenarios.

Fishing Effort Sub-Model

A central analytical challenge facing managers on the West Coast is to determine the spatial extent of trawl and fixed gear fisheries in order to gauge where in the ocean fishing effort is concentrated. This, in turn, is key for assessing the socioeconomic implications of reducing certain sectors of the fleet and the effects of area closures and for determining the likely habitat interactions of particular gear types. In the absence of a comprehensive observer program (data from the first year of West Coast observer program are expected in early 2003) or vessel monitoring systems, there is considerable uncertainty about where vessels using gear types other than trawl gear are fishing.

The OCEAN effort sub-model essentially consists of a sequence of steps, programmed in ArcINFO, which successively constrain each landing record and subsequently apportion catch and revenue to equal area analysis units (9-km × 9-km blocks) based on probability of fishing activity in an area. In contrast to multivariate analysis used in terrestrial applications, which generally predicts what happens in a particular location (e.g., Hargrove and Hoffman 2000), we try to predict the location for known entities. Given the data volume and processing constraints, we are evaluating a statistical approach for future iterations of this project, especially if they involve fine-scale (e.g., daily) data. The following steps characterize this process; Figure 1 shows a flow chart of the model:

> (1) Each PacFIN record contains information on the gear used, species caught, landing port, vessel information, and 1 of 12 statistical management areas where the catch originated;
>
> (2) Impose a maximum range from the landing port that a vessel is likely to have fished, given its length and gear type used. This is currently derived from expert witness testimonies, pending more formal studies of fishing behavior on the West Coast;
>
> (3) Impose depth restrictions on fishing gear used and target species. There are limits to the depth from which West Coast trawlers can haul their nets, or in what depth various fixed gear types are used; similarly, different species of fish have known ranges of bathymetric associations;
>
> (4) Compare this to the species distribution densities derived from the fishery-independent surveys. Some areas are associated with higher frequencies of the target species in question, making it more likely that a fishing vessel would have gone there for its catch;
>
> (5) Within that maximum range, weight the species density clusters inversely by distance from port. This is a "friction of distance" idea; because travel is costly, vessels tend to fish closer to port even if they are slightly less likely to encounter the target species;
>
> (6) Impose habitat restrictions on fishing gear used. Trawlers do not operate in high-relief areas, but these same areas tend to be frequented differentially by vessels using hook and line gear;
>
> (7) Apportion pounds caught and associated revenue to fishing blocks within the maximum range based on probabilities derived from distance from port, targeted species densities, habitat restrictions, and previous activity;
>
> (8) Repeat for all records, and map the resulting distribution of fishing activity. In principle, this can be normalized by number of records associated with an area or, in the case of trawlers, number and duration of tows made there, to provide a measure of effort.

The result of these computations is a GIS data set consisting of the distribution of pounds per species and associated revenues caught with different gear types in different areas on the continental shelf (see Figure 2). It is important to note that this constitutes a spatial reinterpretation of historic data. While it is conceivable to turn this into a predictive model, a major confounder lies in the absence of behavioral models of the fishery. In other words, there are few, if any, known rules that describe fleet behavior, and most economic models that attempt this are based on simplistic assumptions about rational actors and individual profit maximizing considerations. Also, the model in its current form is deterministic, effectively attributing catch and revenues to particular locations. We are currently working on a probabilistic version of the model.

Sensitivity of the OCEAN Analysis

There are two kinds of uncertainty associated with the OCEAN analysis. First, as a meta-model, it is only as good as the various inputs. In the section on data sources and throughout the text, we discuss some of the known problems with the data used in our analysis. These include possible transcription errors and omissions in the PacFIN data, instrument and interpretation errors in the bathymetry data, temporal mismatches between current industry infrastructure and that assumed in the FEAM model, and the manifold issues around census data. Since testing or

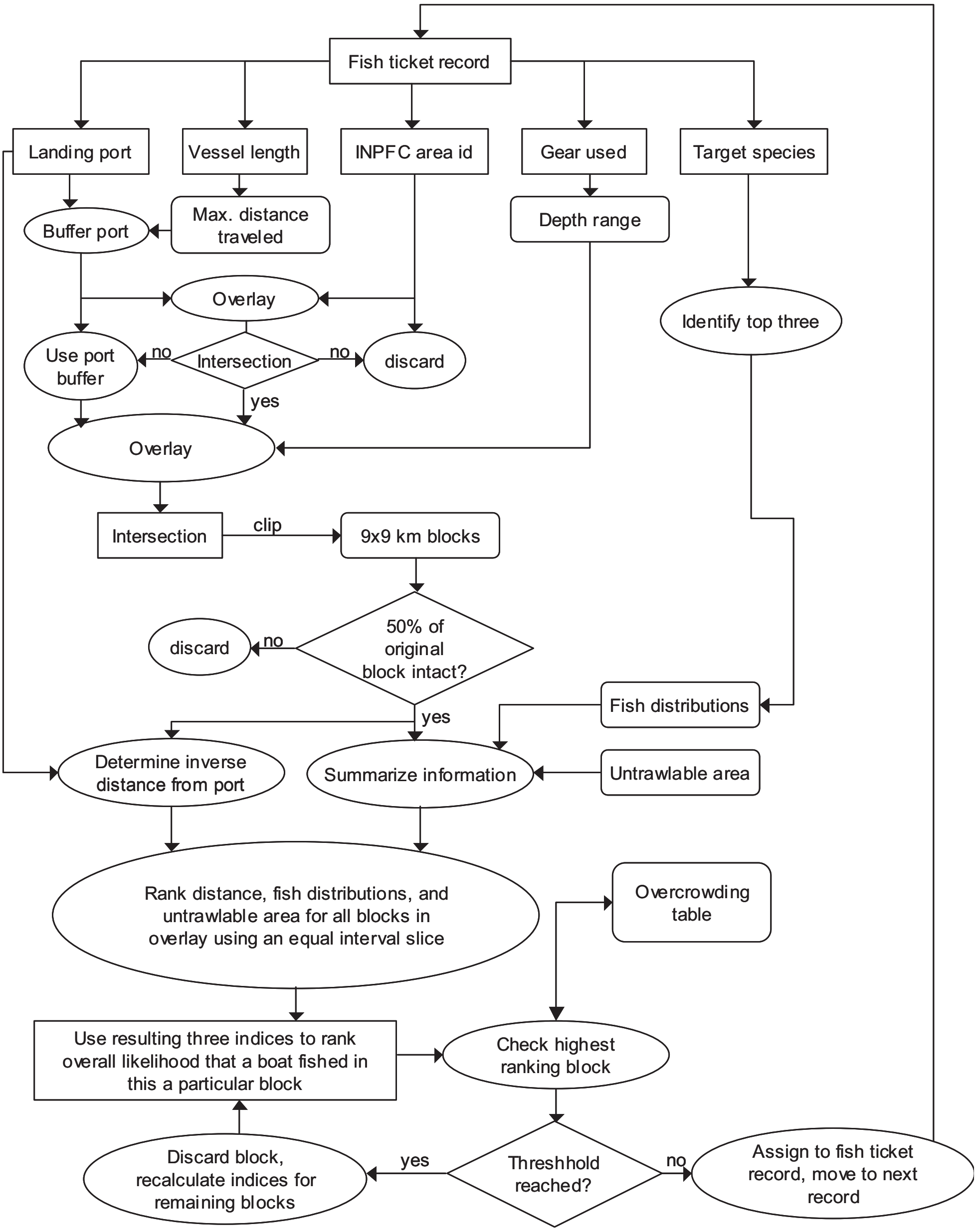

Figure 1. Effort model flow chart.

improving any or all of these data sources was beyond the scope of our project, we took these inputs as a given. The second kind of uncertainty pertains to the model we constructed using these data inputs, notably the fishing effort model. Short of observing whether vessels actually fish where our model predicts they fish, there are few ways to test the accuracy of our model. Therefore, we tested the relative importance of various parameters and assumptions on the outcome of the model. The remainder of this section details a sensitivity analysis of the spatial interpretation of fishing effort.

Due to processing constraints, we performed a sensitivity analysis on a subset of the entire data set, using line item (i.e., per trip) landing receipts for the port of Eureka, California, in 2000. This port is interesting for two reasons: (1) the fleet is fairly well stratified in terms of gear

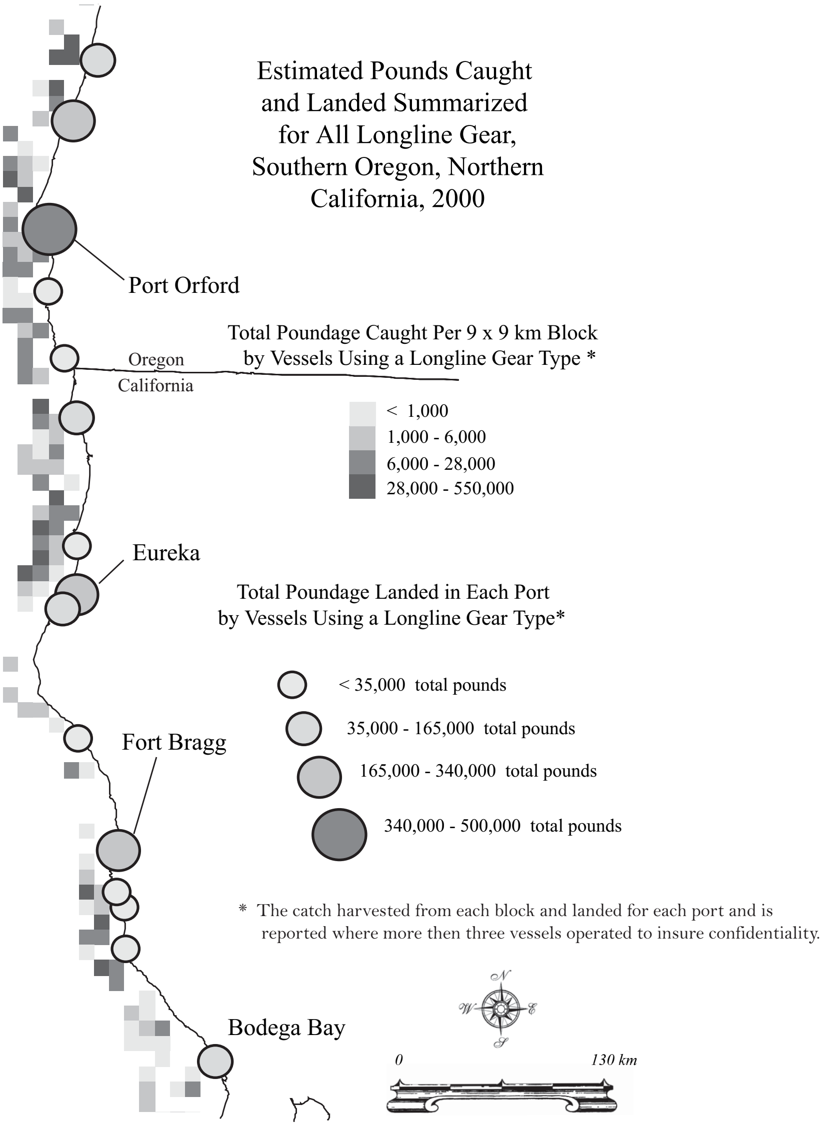

Figure 2. Sample output of effort model.

types used and vessel sizes represented, and (2) it is located in California, where landing receipts for all gear types are referenced by 10-min management blocks, thus providing some measure of accuracy against which to compare our results. There are known problems with the California logbooks because of the widespread strategic reporting that took place in earlier years. Also, landing receipts are filled out by fish buyers and processors. Since these may or may not verify the catch location with the skipper, there is some inherent uncertainty as to their accuracy that we could not control for.

As apparent from Figure 1, there are two distinct sets of variables that are used to predict fishing activity: data inputs used to predict the area where fishing is likely to occur (constraining inputs) and parameters used to predict how catch and effort is spatially distributed within that area (weighting parameters).

We analyzed the constraining variables with respect to their effects on the model results by removing data inputs one at a time, re-running the model, and comparing the difference of total probable fishing area after each iteration. To do so, we adapted a technique described in Crosetto and Crosetto (2002). We quantified the differences between these iterations in terms of the total number of blocks per record. In other words, in the control scenario (with all variables used), each record is associated with a fishing area measured in a number of spatial units (blocks). Removing a particular data input (e.g., distance from port) results in a change in the area associated with that record and, consequently, with the number of blocks. We then calculated the mean number of blocks per record and determined the variance, standard deviation, percent change from the control scenario (i.e., using all variables), and the coefficient of variation (median centered) for the entire fleet as well as for individual gear types (Table 1).

As expected, of the variables tested, the maximum distance from port had the greatest constraining effect. This varies for different fishing gears. For example, results for trawl gear are less affected by distance from port, probably due to their greater range associated with the larger vessel sizes. Furthermore, in some cases, such as hook and line, the model appears sensitive to management area. This is most likely a result of the small sample size. However, no parameter by itself influenced the results of the model substantially. For this reason, we assume that any error originating from the data inputs used for constraining probable fishing areas is not propagated through the model.

Both the gear depth association and the distance from port are assumed variables, derived from expert testimonials. Because of the sensitivity to these two parameters, the model could be greatly improved by calibrating these parameters with empirical data, especially as observer coverage for the study area becomes more readily available.

We tested the sensitivity of the model to the second set of variables (i.e., those used to weight the distribution of catch and effort within the predicted fishing areas) by adjusting parameters incrementally to identify ranges of greatest effect. We analyzed the results from this analysis by summing the total pounds apportioned to each block based on the probability of effort occurring in any given block. The sum of the squared variation and the coefficient of variation were then calculated for each iteration. Figure 3 shows the variation of the effects of adjusting individual parameters (based on the coefficient of variation). Individual parameters were adjusted from no-effect to four times the effect (relatively), while other parameters were held constant (in this case at a relative weight of 100). Results are based on variation from the zero-based effect (relative weight of 1).

While Figure 2 does not explain the importance of any given parameter in relation to the others, it does describe the magnitude of variation resulting from adjustment of the given case (i.e., how much the results change in response to changes in one parameter). The effort model is most sensitive to weights given to the overcrowding potential. A minor change in the weight of the parameter results in a dramatic difference in the spatial distribution of catch. Additionally, variance resulting from adjusting the overcrowding parameter begins to decrease after weights exceed three times that of other parameters. This is due to a maximization of the effects of overcrowding resulting from equal distribution of catch. That is, the effects of overcrowding become so influential on the model that any activity results in a shift in behavior for all areas associated with a record, and these effects begin to cancel each other out.

The model is also quite sensitive to changes in the relative weight given to untrawlable areas. It appears, however, that the variation of effects that this parameter has on the results tends to flatten out after it has been weighted to three times that of the other parameters. This is due, in part,

Table 1. Effects of selectivity removing various data inputs. INPFC = International North Pacific Fisheries Commission.

Variable removed from analysis	Min	Max	Mean number of blocks	SD	Perecent difference	Coefficient of variation
Control (no parameters removed)	3	223	107.74	52.98	-	-
Trawl gears	9	223	130.37	34.63	-	-
Hook and line	2	43	18.97	11.54	-	-
Longline	4	36	26.48	7.67	-	-
INPFC management area	9	375	149.36	80.10	138.63%	64.60%
Trawl gears	42	375	181.44	58.56	139.17%	17.10%
Hook and line	9	67	26.44	15.66	139.35%	254.80%
Longline	12	44	33.77	5.09	127.50%	152.80%
Distance from port	43	1,107	188.61	90.77	126.28%	229.50%
Trawl gears	43	929	226.03	59.80	124.57%	107.60%
Hook and line	43	117	55.76	28.07	210.89%	409.60%
Longline	43	117	50.53	22.39	149.66%	464.90%
Gear/depth association	4	269	150.64	50.09	79.87%	98.30%
Trawl gears	34	269	168.31	37.59	74.46%	60.30%
Hook and line	4	269	67.20	69.81	120.52%	45.70%
Longline	14	159	89.00	30.09	176.11%	17.90%

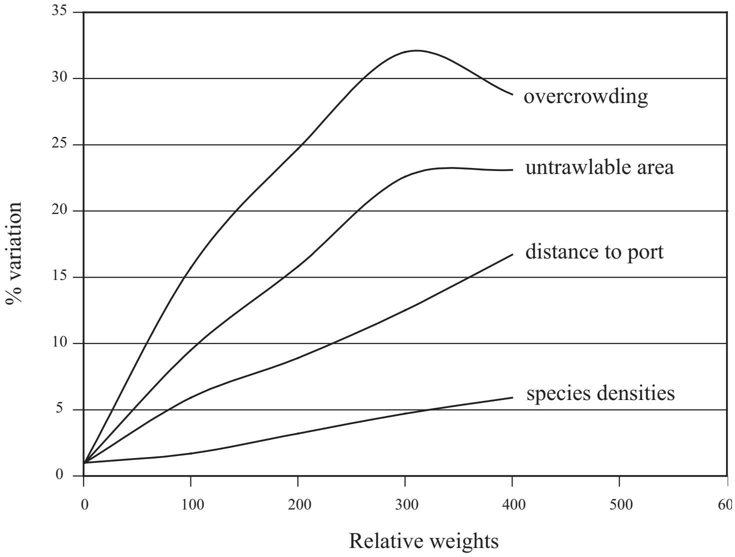

Figure 3. Coefficient of variation of weighting parameters.

to the limited number of analysis units containing untrawlable areas. The magnitude of importance of these areas quickly becomes limited by other parameters (such as overcrowding).

The sensitivity analysis helps in determining the parameters that influence the results of the model the most and, therefore, warrant the most attention in terms of obtaining empirical data for the purpose of calibration. From our analysis, it is apparent that different assumptions made about overcrowding of specific fishing grounds and the distance a boat will travel from port will result in considerably different distributions of catch and effort. Extra care, therefore, should be taken in empirically verifying these assumptions.

Application to West Coast Groundfish Fleet Restructuring

We now turn to the analysis of a suite of coast-wide management scenarios related to the restructuring of the West Coast groundfish fleet. The starting point for the analysis in Ecotrust's Groundfish Fleet Restructuring (GFR) project (2001–2003) was the strategic plan that the PFMC adopted in 2000, the first priority of which is the reduction of fishing capacity by at least 50% in each sector (PFMC 2000a). Fishing capacity is notoriously difficult to measure, since it is a combination of number and size of vessels, their technical efficiency (i.e., fish-hold capacity, horse power, volume, and efficiency of nets and other gear), and the time commitment of fishermen (Smith and Hanna 1990; Federal Fisheries Investment Task Force 1999; Gréboval 1999). Of these factors, only the number and size (length) of vessels is well documented on the West Coast. While technical efficiency is generally assumed to have increased over time, estimating the physical capacity of the fleet is hampered by the absence of comprehensive data about specific vessel characteristics outlined above. What we do know about the fleet is almost entirely limited to fish tickets and logbooks, which record mainly how much has been landed. This, however, is increasingly determined by market and regulatory factors and is not an accurate reflection of the true capacity of the fleet—only of what it is allowed to land. In other words, landings are not so much an indicator of capacity as of what the fleet is allowed to catch, whereas capacity is a measure of what it could potentially catch. The National Oceanic and Atmospheric Administration is working on quantitative measures of the capacity of U.S. fishing fleets (Offices of Science and Technology and Sustainable Fisheries 2001), but a comprehensive set of capacity measures is not yet available.

Capacity Estimates

On the West Coast, the PFMC's Scientific and Statistical Committee (SSC) Economics Subcommittee (SSC 2000) has estimated the rate of the capacity utilization (i.e., the ratio of catch to capacity) in the groundfish fishery. Using landings from earlier, less-constrained periods together with current fleet sizes, the underlying capacity of the fleet can be inferred. The assumption is that vessels were fishing at or close to their capacity in earlier, relatively unconstrained time periods. In the case of the West Coast groundfish fishery, the distinction is typically made between pre-1994 and post-1994 fishing seasons when the present limited entry regime was implemented and vessels either qualified for limited entry (LE) permits or remained in the open access (OA) fishery. Using the 1995–1998 participation in the fishery by fleet sectors and permit status, in other words, open access, limited entry trawl, limited entry nontrawl/sablefish, and limited entry nontrawl/nonsablefish, vessels were assigned LE or OA status in earlier years. This assumes considerable temporal homogeneity of the fleet and basically codes vessels in earlier years by the fleet sector they participated in later. Considering the landing histories of each fleet sector prior to 1994, the SSC analysis then estimated the number of vessels needed in each of the earlier years to catch 2000 harvest targets defined for each sector. The resulting capacity utilization rates are an expression, therefore, of how many vessels fishing at relatively unconstrained capacities would have been needed to catch the allocations for each fleet sector in 2000. The SSC analysis found capacity utilization rates ranging from 6% in the open access to around 40% in the limited entry trawl fleet sectors (SSC 2000). Thus,there is considerable excess capacity in the West Coast groundfish fleet, as is the case for many commercial fisheries.

We applied the same logic to our data set and derived the number of vessels in each of the four fleet sectors in 2000. Table 2 summarizes our and the SSC's findings as well as the inferred number of vessels needed in each sector from the SSC study. In the open access and limited entry trawl fleets, we derived somewhat higher capacity utilization rates. These should not be read as an improvement of the capacity problem but rather a reflection of the incongruities between the two data sets. Also, we decided to use our 2000 figure for the number of distinct vessels in the open access (614) fleet rather than the 1995–1998 average (980, which was higher than the SSC's average of 910) because we believe that this reflects trends in the open access fleet better. Our capacity utilization rates for the limited entry nontrawl fleet are lower than those derived in the SSC study. We believe this is a function of our data set: since PacFIN distributes catches of rockfish across vessels and areas, our annualized data do not allow for sufficient distinction between targeted and bycatch harvest strategies for sablefish and rockfish caught in the LE fixed gear fleet. We also found a high degree of overlap between vessels in the LE nontrawl sector: most of these fish for both sablefish and rockfish, and only 16 vessels target sablefish exclusively. The SSC inferred a need for 40 nontrawl LE vessels total, of which 15 are needed to harvest the sablefish target. In our reduction scenarios, therefore, we apply the reduction logic to the entire LE nontrawl sector, and treat the 16 sablefish-only vessels separately.

We used these capacity utilization estimates to identify a subset of vessels for removal from the fleet based on a number of different criteria that simulate some prominent policy considerations:

Table 2. Summary of Groundfish Fleet Restructuring (GFR) and Scientific and Statistical Committee (SSC) capacity calculations. The numbers in bold are used in the subsequent scenario analysis; table contains double counts of vessels that occur in more than one size category in information received from PacFIN. This is one of many factors that makes accurate counts of vessels challenging. OA = open access; LE = limited entry.

	GFR			SSC		
Fleet sector	Number of vessels	Number of distinct vessels	Capacity utilization estimates	Number of vessels	Inferred number of vessels needed	Capacity utilization estimates
OA (2000)	1,524					
OA with groundfish landings > 0.25 MT (2000)	713	**614**	**7% (low); 14% (high)**		**50 (low); 100 (high)**	
OA with groundfish landings > 0.25 MT (1996-1998 average)	983			910	50 (low); 100 (high)	5.5% (low) 11% (high)
LE trawl (2000)	452	**244**	**45.5%**	274	**107**	39%
LE non-trawl (2000)						
Non-sablefish	279	**177**	**14.3%**	232	**40**	17.2%
Sablefish	228	176	6.6%	164	**15**	9.1%
Sablefish exclusive		**16**	**100% (assumed)**			

(a) Reducing all excess capacity. Given the estimates of how many vessels are needed to harvest the 2000 harvest targets, we consider what the fishery would look like if only the highest producing vessels up to the level needed were harvesting;

(b) Reducing capacity by 50% in each sector. This is the PFMC priority articulated in the strategic plan. Since the council has not yet identified reduction mechanisms for all sectors, we randomly selected half of the vessels in each. So far, the council has only identified a reduction mechanism for the trawl sector, a part government, part industry financed buyback of qualifying trawl vessels, which are to be identified in a reverse auction. Reducing capacity by 50% in each sector while preserving fleet diversity takes into consideration the strategic plan goal to preserve fleet diversity, which we interpret here as preserving the proportions of different vessel lengths present in each fleet sector in the base year, 2000;

(c) Reducing capacity in each sector while preserving economic viability. This reduces capacity not to or by a given percentage but, rather, preserves all those vessels that currently achieve a minimum level of exvessel revenues from groundfish landings in each sector (i.e., irrespective of where they are operating with regard to capacity estimates). We set these revenue levels, somewhat arbitrarily, as follows: LE trawl, more than US$50,000; LE nontrawl/nonsable, more than $10,000; LE nontrawl/sable, more than $20,000; and OA, more than $5,000. In other words, for a vessel to remain in, for example, the LE trawl sector, it has to have at least $50,000 groundfish exvessel revenues in the base year, 2000.

We then compared the "before" and "after" effects of removing vessels according to these criteria, using the 2000 fishery as a baseline. The immediate effect is to diminish revenues and landings associated with vessels exiting the fleet. Since total landings are a function of allowable harvest limits, and since these would not necessarily change in a capacity reduction exercise, a redistribution of landings and revenues (and with it the associated income and other community impacts) along the coast takes place. In the medium to long term, vessels remaining in the fleet would harvest the difference resulting from the reduction to the harvest targets. Thus, the immediate impacts are not the ultimate outcome of a capacity reduction. They do, however, indicate the order of magnitude of the wealth transferred between vessels exiting and vessels remaining in the fleet.

Vessels remaining in the fleet are better off since they compete with fewer boats for the total allowable catch. Their trip limits increase, and they bring more landings and revenues into their port—presumably up to the total of coast-wide landings and revenues from groundfish in 2000. The difference between the "before" and "after" levels of landings and revenues, therefore, accrues to vessels remaining in the fleet. Indeed, to the extent that the remainder of the fleet is successfully managed to achieve stock rebuilding objectives, total allowable catches may even increase. Those ports associated with vessels removed from the fleet, however, experience a corresponding decline in landings and revenues. For them, the "after" effect of our various scenarios may be permanent and can be interpreted as a cost associated with a fleet reduction measure.

Summary of Capacity Reduction Scenarios

The results of the four numeric reduction scenarios are summarized in Table 3 below. We focus on two central aspects of fleet reductions: (1) the landings, exvessel revenues, and associated income that are redistributed from the vessels exiting the fishery to the remainder of the fleet and (2) the effects on overall size and composition of the fleet. There are many more issues that can be explored with OCEAN than can be discussed in this paper. In particular, we only compare the coast-wide results of the scenarios. It is possible to examine the effects down to the level of individual ports (Scholz 2003), which is of considerable interest to our community partners.

From Table 3, it is apparent that even at the coast-wide scale, different reduction schemes have substantially different effects on the fleet. There are three notable results. First, the effects of removing all excess capacity and removing 50% of capacity are remarkably similar. Recall that scenario 1 removes the entire excess capacity, and only the numbers of vessels per fleet sector needed to harvest the 2000 targets remain in the fleet. The overall effect is comparable to that of a 50% capacity reduction, both in terms of the initial reductions, landings, and revenues and the amount of income effectively redistributed from the exiting vessels to those remaining. Indeed, since scenario 1 was selected for the highest producers, this occurs at a smaller initial decline in exvessel revenues than in the random selection process of scenario 2. To the extent that income impacts can be thought of as the "cost" of capacity reduction, a coast-wide reduction of fleet capacity can thus be achieved for between $70 million and $75 million. Coast-wide, the effect on fleet composition is most pronounced when removing all excess capacity to the level of only 50 distinct open access vessels. Not surprisingly, the share of the smallest vessel class, VS 1, drops.

Secondly, selecting for a diverse remaining fleet imposes significantly lower costs (in terms of the income redistributed) on the coast. In other words, reducing fleet

Table 3. Summary of fleet reduction scenarios. OA = open access; LE = limited entry.

Value	Base (2000)	Initial value of fleet reamining after capacity reduction				
		Scenario 1 (50 OA reamining)	Scenario 1 (100 OA remaining)	Scenario 2 (random)	Scenario 3 (diversity)	Scenario 4 (viability)
Coast-wide landings (pounds)	272,390,187	123,131,582	123,772,655	132,480,150	153,934,597	181,145,380
Change from base		–55%	–55%	–51%	–43%	–33%
Coast-wide revenues (US$)	62,141,810	36,127,210	37,274,029	30,509,611	43,664,904	47,744,959
Change from base		–42%	–40%	–51%	–30%	–23%
Coast-wide income impacts (US$)	138,961,151	63,832,802	65,180,144	68,244,427	90,997,105	101,667,573
Income redistributed (change from base; US$)	0	75,128,349	73,781,007	70,716,723	47,964,046	37,293,578
Income change	0%	–54%	–53%	–51%	–35%	–27%
Implied multiplier (US$/pound)	0.51	0.52	0.53	0.52	0.59	0.56
Number of vessels[a]	2,427	986	1,011	1,212	1,464	1,499
LE trawl	642	344	344	311	378	553
LE non-trawl, non sablefish	422	143	143	210	255	152
LE sablefish exclusive	25	25	25	11	17	21
Open access	1,339	174	499	680	814	773
Fleet diversity (%) of total fleet						
VS1	39%	26%	37%	40%	39%	38%
VS2	37%	29%	27%	37%	36%	32%
VS3	18%	35%	28%	17%	17%	23%
VS4	5%	9%	7%	3%	6%	6%
VS5	0%	0%	0%	0%	0%	0%
VS6	1%	1%	1%	3%	2%	1%

[a] Note: Revenue, landings and income estimates are based on the unique vessels identified in the capacity calculation. Each vessel, however, has multiple instances as a function of making landings in multiple ports and using multiple gears over the course of a year. The numbers reported in this table report these per port "vessel-gear instances." So in the base year, there were, for example, 642 gear-port combinations of the 244 vessels in the LE trawl sector.

capacity by 50% in each vessel size-class in each sector achieves the same reduction of vessels but at the smaller redistributive "price" of around $48 million. Also, consider the meaning of the multiplier: each pound landed has an income "footprint." The fleet remaining after scenario 3 has a larger income footprint than the other scenarios. In other words, each pound caught generates more income than the same pound caught in a differently configured fleet. The total amount of income redistributed from the vessels exiting to those remaining is around $50 million. Since the number and sizes of vessels remaining in the fleet have a different geographic distribution than in scenarios 1 and 2, the effects of this scenario are also distributed differently. In comparison to the random reduction of 50% in each fleet sector, the overall fleet composition remains the same but with more vessel instances (1,464 versus 1,212) and, thus, with more associated income and jobs.

Finally, scenario 4 suggests that economic viability may be a useful consideration in designing capacity reduction measures. Recall that this scenario is based on some explicit and not entirely realistic assumptions about levels of exvessel revenues derived from groundfish needed to "make a living." Since these economic constraints can be translated into vessels to select for removal from the fleet, there are clear effects on the size, composition, and distribution of the remaining fleet. It would be interesting to examine the economic viability criterion in conjunction with numeric reduction targets. Interestingly, the particular set of economic viability criteria we chose had the effect of increasing the share of vessels in the 18–24-m (60–80-ft) range (VS 3). This illustrates the fleet composition effects of fleet reductions, which can be explicitly considered in the GFR framework.

The local implications of these scenarios differ along the coast. Figure 4 shows the amount of income generated by fishing in 2000, aggregated by port group from south to north. To the right of the base column for each port group are the income impacts of each scenario (i.e., the amount of harvester and processor income generated by the vessels remaining after the reduction). As is evident from the graph, some scenarios (notably the economic viability one) result in some ports maintaining income levels at pre-reduction levels (e.g., the Monterey Bay area or ports in the Eureka area). Also, the income effects suggest that economic viability concerns may be more important in some ports than in others. For example, Eureka; Coos Bay, Oregon; and Newport, California, areas fare better in terms of income associated from landings by the remainder of the fleet under the economic viability scenario than the fleet diversity one, whereas there is little difference for Astoria, Oregon, or the Northern Puget Sound, Washington, area. Recall, however, that the economic viability criteria were set rather low, thus retaining more vessels in the fleet than under more realistic constraints.

Figure 4 is properly interpreted as the level of income generated in each port group immediately after each reduction scenario is implemented, by the vessels that were making landings in those ports before. The dynamic response of the fishery to each scenario cannot be inferred. In particular, it is not clear how the landings formerly accruing to the vessels exiting the fishery would be allocated among the remainder of the fleet. This offsetting effect on port-reduction income levels could be approximated by making some assumptions about the remainder of the fleet. For example, one could reasonably assume that vessels remaining in the fleet would harvest the now "surplus" allocation according to the same proportions as they did before. Alternatively, one could impose some new allocation rules such as gear requirement on the remainder of the fleet. The fleet composition effects summarized for the entire coast in Table 3 are considerably more pronounced at the local level, where some scenarios eliminate entire vessel size and gear classes in some ports.

It is important to note that our analysis assumes that the total possible harvest remains unchanged (i.e., that there is no net reduction in the harvest allocations in conjunction with a fleet reduction). Specifically, for our 2000 baseline this means that the remainder of the fleet is catching the same total poundage as the fleet prior to the reductions. In light of the increasingly more stringent measures necessitated by rebuilding plans and other considerations, there may be a concomitant reduction of the overall harvest. In that case, there would be income impacts in addition to the redistribution effect between exiting and remaining vessels we consider here.

Effects of Area Closures

Another application of OCEAN lies in assessing the ecological, economic, and community effects of area closures. These have recently come to more prominence in the groundfish fishery with large closures off the West Coast to protect vulnerable species, notably the Cowcod Closure Areas in effect off Southern California since 2000 and the in-season shelf closures put into effect in the federal fishery in June and September 2002. Similar time–area closures continue in the 2003 fishery and, given the slow rebuilding rates of many rockfishes and other species of concern, are likely to shape fishery management for many years to come.

Implicit in area-based management measures is a displacement effect on fishing vessels. Depending on the size and depth covered by closure area, some vessels may be induced to exit the fishery. For example, the 2002 in-season shelf closures affected depth between 100 and 250 fathoms; fishing farther offshore, to the west of the closure area is only feasible for a subset of the fishing fleet,

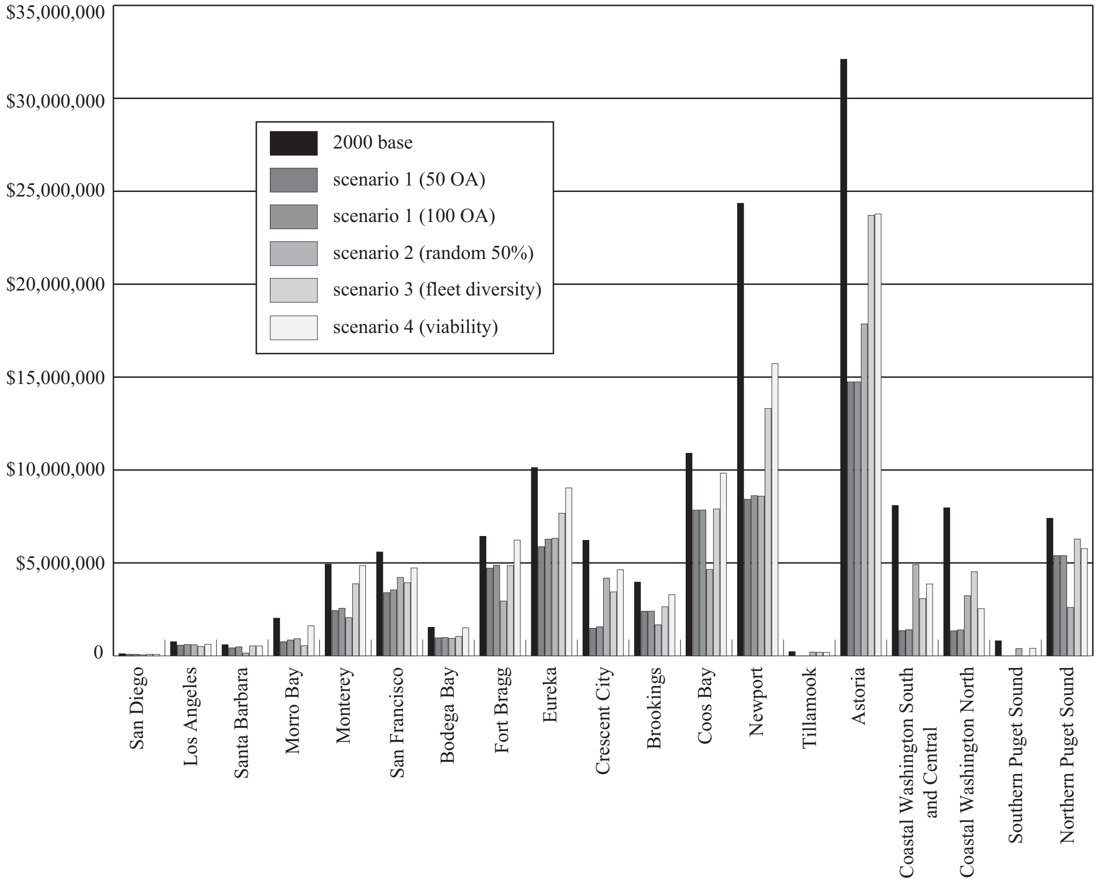

Figure 4. Summary of local impacts of scenarios along the coast.

vessels with sufficiently large engines and deepwater gear. Not all of the vessels that used to fish in the closure area will successfully relocate closer inshore. As an initial estimate of the potential displacement effect, in economic terms, we investigated the 2002 in-season closures in our framework. Figure 5 shows the extent of the shelf closure.

Using the 2000 fleet and effort distributions as a baseline, we identified the number and types (by gear, size, and species targeted) of vessels that fished in the closure area. Assuming that the same vessels would have fished there in 2002, we then computed the coast-wide income impacts associated with the landings initially lost due to the closure. Again, since this is a static analysis, we did not consider the adaptive effects, and, consequently, the estimates constitute the upper bound of the wealth effect. For the total coast, the income impacts generated by landings outside the closure area amount to around $115 million, and, thus, the closure potentially results in lost income on the order of $22 million if vessels were permanently displaced. More interestingly, the effects of the shelf closure vary along the coast, since fishing in the shelf areas is of varying importance for different ports, gear groups, and fishing vessels. The effect of the closure, therefore, varies accordingly, as shown in Figure 6.

While ports farther north generally have higher total groundfish landings, the relative effect of the shelf closure area varies considerably. For example, while Eureka and Crescent City, California, appear relatively unaffected, Newport and Astoria experience somewhat of an impact, and a more pronounced effect appears in Coos Bay and northern coastal Washington. Even more revealing is the consideration of the percentage of landings and revenues derived from the shelf closure area, as shown in Figure 7. Although total income derived from groundfish is small in ports like Santa Barbara, they do account for over 50% of landings and revenues derived from groundfish there. In other words, what fishing there is for groundfish is highly dependent on the closed areas, which comprise much of the area around the historically productive Channel Islands, California.

Another important aspect of the geographical differ-

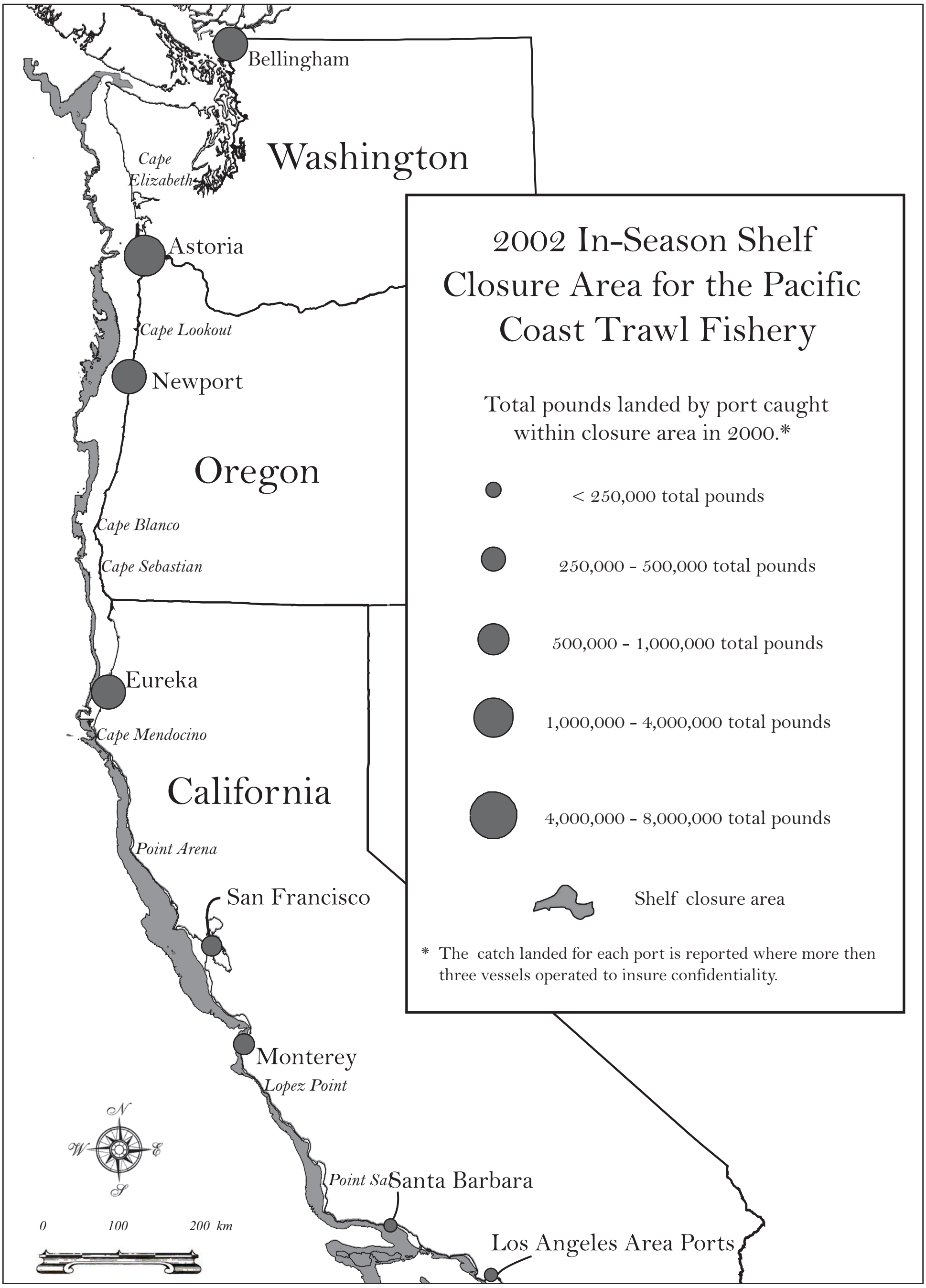

Figure 5. 2002 in-season shelf closure area <this will be replaced by simplified black and white version>

ence of reliance on the shelf closure areas emerges from the difference between landings and revenues. For example, less than 5% of groundfish landings in Newport come from the shelf, but these account for almost 20% in exvessel revenues in this port. This suggests that the shelf closure areas yield relatively more valuable species than do other fishing grounds. Again, there is a geographic differential in reliance on the shelf closure area.

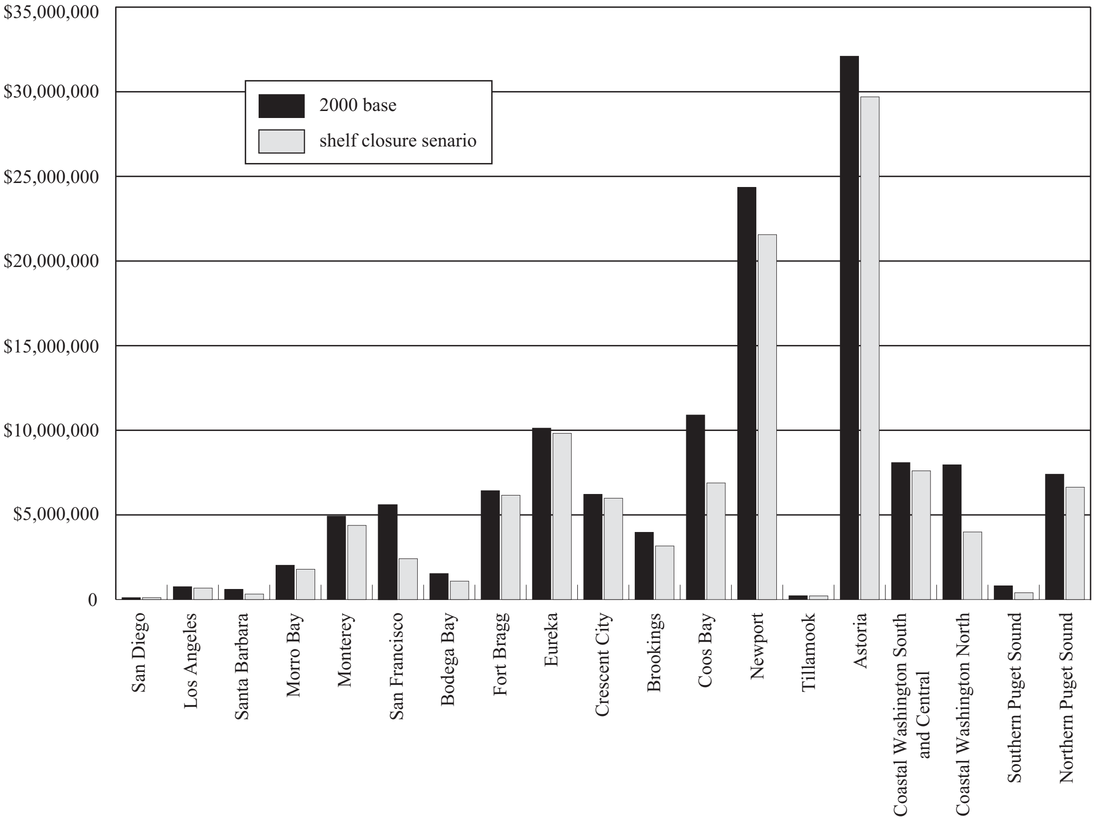

Figure 6. Income impacts before and after 2002 in-season shelf closure.

Conclusions

The analysis and results presented here are illustrative of the kind of assessments that can be conducted with a spatially integrated analytical framework such as OCEAN. By linking a GIS to real-time fishery data and economic impact models, we were able to generate estimates of the effects of fleet reductions and area closures. Even from the static analysis presented here, it is apparent that geography matters: scenarios have location-specific and differential effects in different parts of the coast, on differently composed fleets (by size and gear types), and by the relative reliance on particular species or fishing grounds.

The approach taken here makes use of currently available data and harnesses them in a framework that can be accessed by decision makers and communities directly. A potentially important application of this framework is the assessment of particular fleet reduction strategies—for example, the coast-wide estimates of income that is redistributed from the exiting vessels to the remainder of the fleet is an estimate for an amount that would have to be financed in a buyback program. Similarly, the effects of a fishing quota program could be simulated by constructing rules for which kinds of vessels (based on revenue and landing profiles, ownership, and other characteristics) buy out others.

The first actual capacity reduction measure, a part industry, part government financed buyback of qualifying trawl vessels, was designed before this sort of spatially explicit model was available. In principle, it would be possible not only to assess the habitat implications of removing particular vessels in the buyback but also to analyze whether the trawl buyback accomplishes the essential fish habitat objectives being developed in an as yet unrelated policy process. We are cautiously optimistic that as spatially explicit models such as OCEAN become more commonplace in fishery management, decision makers and stakeholders will seize upon them for investigating synergistic effects (e.g., between habitat protection and increasing the economic feasibility of the fleet).

While there are many conceivable extensions of this approach to predictive modeling, an immediate benefit of OCEAN is that it makes visible the existing data and,

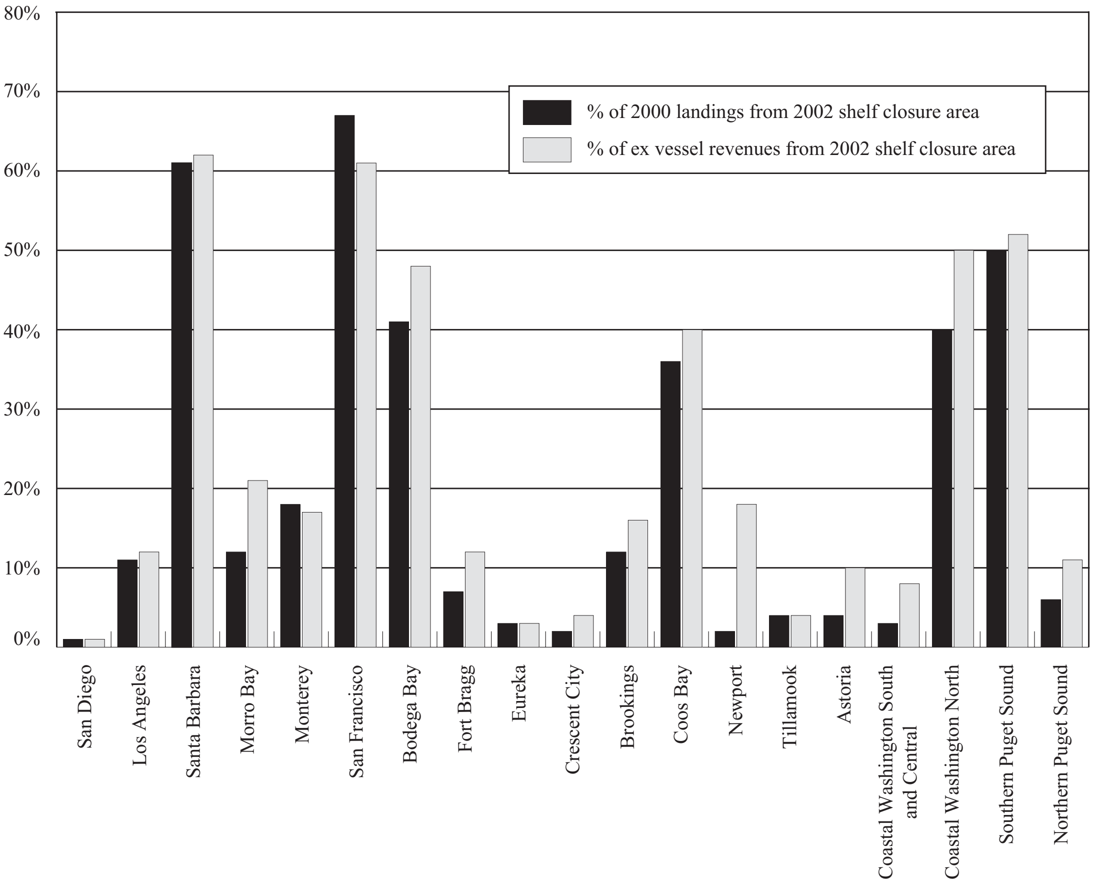

Figure 7. Landings and revenues from inside 2002 shelf closure area.

thus, helps identify gaps and problems with current information sources. In particular, it remains to be seen if the spatial interpretation of historical landing receipts can be validated using the forthcoming observer data on the West Coast or a future vessel monitoring system. The kind of close spatial scrutiny of fishery management measures may also indicate the reprocessing of other data, notably the commercial trawl logbooks.

Acknowledgments

We would like to thank our project partners at the Pacific Marine Conservation Council, and colleagues on the West Coast and elsewhere who reviewed this project in various earlier forms. We are indebted to the over 100 fishermen, scientists, managers, and industry observers who kindly provided background and other information on the fishery and who made numerous valuable contributions to the research design. We thank Marc Mangel for his suggestions and three anonymous reviewers for their thoughtful and constructive criticism. This project was funded by the David and Lucile Packard Foundation, NOAA Fisheries' Northwest Regional office, NOAA's National Marine Protected Area Science Center, the Homeland Foundation, and Oregon Sea Grant.

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